Evaluation of the role of salicylic acid and calcium in improving drought stress tolerance in *Curcuma longa* L.

Synopsis

Submitted in the partial fulfillment for the requirement of

DOCTOR OF PHILOSOPHY

In

Botany

Submitted by

Navneet Kaur

Under the supervision of

Dr. Akbar Ali

Department of Botany, Faculty of Science

Dayalbagh Educational Institute (Deemed to be University)

Dayalbagh, Agra-282005

2022

Introduction

In India, approximately 70% medicines are derived by the help of natural products (Aftab et al., 2019). Natural products have curative properties which are used in the treatment of human diseases, in India in recent times 20,000 medicinal plant and spices have been discovered, 800 plants out of them are phyto-chemically used for cure human disease. The plant-based products are fibers, polysaccharides, dyes, pigments, oils, and other bioactive compounds used in the perfume industry, wood industry, used as coloring agent, and as food additive.

Abiotic stress recognized as the potential treat to agriculture production worldwide. Abiotic stresses such as salinity, drought, temperature, flooding, heavy metal toxicity and radiations are negatively affecting plants natural products. The physiological, biochemical, and molecular processes of the plant influence due to abiotic stress, from germination to maturity stage, with the result of severe reduction in the crop yield and secondary metabolites of plants.

Plant growth regulators play an important role in the development processes and signaling networks, growth regulators directly or indirectly associate with the stress tolerance in plants (Asgher et al., 2015). Plant growth regulators regulate growth and developmental processes in the plants. Various plant growth regulators (PGRs), such as auxin, cytokinin, gibberellins, abscisic acid, brassinosteroids, jasmonic acid, ethylene, salicylic acid, nitric oxide, strigolactones and polyamines found naturally or synthetically.

Salicylic acid is phenolic growth regulators, important in the regulation of physiological processes such nitrogen metabolism, proline metabolism, antioxidant enzyme activity regulation and in plant-water relations under abiotic condition *via* these they provide protection to plant aginst abiotic stress (Miura and Tada, 2014). Salicylic improved salt tolerance (Bastam et al., 2013; Khan et al., 2014; Shaki et al., 2018), drought tolerane (Fayez and Bazid, 2014; Damalas, 2019; Sedaghat et al., 2020), heavy metal tolerance (Islam et al., 2016) and heat tolerance (Khan et al., 2013; Jahan et al., 2019). Salicylic acid also modulates the metabolism of mineral elements and by this salicylic acid improved plant development and physiology under stress conditions (Nazar et al., 2015). Salicylic acid involved in the regulation of uptake of plant beneficial elements such as manganese, calcium, copper, iron, phosphorus, and zinc by minimize oxidative stress under lead stress (Wang et al., 2011).

Plant nutrient has important role in crop production. In the absence of the essential nutrient plant fails to grow and complete their life cycle. Nutrients are the limiting factor for plant growth in accordance to Liebig's law of minimum. Some mineral elements is essential for plant growth and development *viz.* carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorous (P), sulphur (S), potassium (K), iron (Fe), maganesium (Mg), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni), chlorine (Cl) and sodium (Na). Mineral nutrient availability is important for plant because plant nutrient help to maintain basic physiological such as photosynthesis, respiration process and metabolic process such as enzymes catalysis, and osmosis. Stress and mineral nutrients are correlated with each other like, under drought condition. Moisture reduction resulting less nitrogen (N) absorbed by the plants, ultimately reduce plant growth and developments processes.

Calcium is an important nutrient element, known for many growth and developmental role under normal and stress condition in plants. Calcium acts as major secondary messenger molecule in plant under various stress condition (Kader and Lindberg, 2010).

Salicylic acid and Calcium interaction might be involved in the defense mechanism under stress condition and maintain potassium and sodium ion selectivity (Liu and Zhu, 1997). Salicylic acid induced calmodulin-binding protein under abiotic stressed.

Curcuma longa L. (Turmeric) is an aromatic and important medicinal plant belongs to family Zingiberaceae with immense potential as medicine, in cooking as spice, as coloring agent or dye (Das, 2016). Turmeric is herbaceous perennial herb, grown as annual as well as biennial also. Turmeric rhizome used worldwide specifically in Asian countries (Akaberi et al., 2021). 100 species of curcuma found worldwide, 41 out of them found in India, 10 out of 41 are endemic to the India (Nair, 2019). *C. aeruginosa, C. albiflora, C. amada, C. amarissim, C. angustifolia, C. aromatic, C. caesia, C. caulina, C. comosa, C. petiolata, C. decipiens, C. rubescens, C. ferruginea, C. longa, C. Montana, C. neilgherrensis, C. oligantha, C. pseudomontana, C. reclinata, C. xanthorrhiza, C. zedoaria, C. sylvatica, C. aurantiaca, C. sulcata, C. indora, C. ecalcarata, C. soloensis, C. brog, C. haritha, C. raktakanta, C. kudagensis, C. thalakaveriensis, C. malabarica, C. karnatakensis, C. cannanorensis, C. vamana, C. lutea, C. coriacea, C. nilamburensis,* and *C. leucorhiza* (Velayudhan et al., 1999).

Review of literature

Classification and Description of *Curcuma longa* L.

Kingdom	Plantae
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Mangnoliopsida
Order	Zingiberales
Family	Zingiberaceae
Genus	Curcuma
Species	*Longa*

Source: Integrated Taxonomic Information Systems – Report

Origin and Distribution

Turmeric is native to Southeast Asia and the diversely found in tropical area of the world. The greatest diversity found in India, Thailand, and Myanmar (Nair, 2019). *Curcuma longa* L. found throughout India, but Andhra Pradesh, Tamil Nadu, Odisha, Karnataka, and West Bengal are the major turmeric producing state.

Verities

The cultivars of *Curcuma longa* include many cultivars *viz*. Kesari Duvvur, Amruthapani Kothapeta, Duggairala, Tekurpeta, Mydukur, Armoor, Sugandham, Vontimitta, Nandyal, Avanigadda, Erode, Salem, Alleppey, Mannuthy local, Shillong, Tall Karbi, Rajapuri, and Eavaigon. The name of these cultivars acquired where they grow widely (Nair et al., 1980; Nair, 2019).

Phytochemistry of *Curcuma longa* L.

Various biochemical components found in *C. longa* L. extract, such as curcuminoids (1-6%), dietary fiber (2-7%), essential oil (3-7%), dietary minerals (3-7%), fat (5-6%), protein (6-8%), water (6-13%) and carbohydrates (60-70%). *C. longa* L. rhizome has volatiles and non-volatiles substances. The non-volatiles substances from *C. longa* L. are coloring agents, and the major bioactive substances of *C. longa* L. are curcuminioids (rich source of phenolic compounds) such as curcumin, demethoxycurcumin and bisdemethoxycurcumin (Nelson et al., 2017).

Essential oil extracted from its rhizome as well as from leaves also β-pinene, myrcene, α-phellandrene, δ-3-carene, α-terpinene, o-cymene, eucalyptol, terpinolene, α-zingiberene, β-sesquiphellandrene, ar-

turmerone are the constituents of oil extracted from its leaves while α-thujene, camphene, α-phellandrene, ρ-cymene, ο-cymene, eucalyptol, terpinolene, α-terpineol, α-cis-bergamotene, ar-curcumene, υ- himachalene, (e, e)-α-farnesene, cis-α-bisabolene, ar-turmerone are found in the rhizome oil (Sandeep et al., 2021). The aroma in the turmeric oil is due to ar-turmerone (Champakam and parthasarthy 2008).

Pharmacological properties

Turmeric rhizome exhibits various pharmacological activities which is beneficial in human health. It has anti-bactrerial (Esmaeili et al., 2018; Kebede et al., 2021), anti-fungal (Ogidi et al., 2021; Prajapati et al., 2021), anti-inflammatory (Meizarini et al., 2018; Mattai 2020), antioxidant (Jayaprakasha et al., 2002; Tilak et al 2004; Singh et al., 2010; Akter et al., 2019; Yang et al., 2020), anti-tumor (Hay et al., 2019), and anti-viral (Colpitts et al., 2014) properties.

Applications of *Curcuma longa* L.

Curcumin is a yellow-colored bioactive compound found in *C. longa L*. rhizomes. It has wide range of applications in pharmacy, food, and cosmetic industry. Their essential oil used in the flavor, perfumery, beverages, and the pharmaceutical.

***Curcuma longa* L.**

Vineeth et al., (2014) treated *Curcuma longa* L. with calcium hydroxide under heavy metals stress. They concluded that medicinal plant *Curcuma longa* affected with heavy metals can be treated by using 1% calcium hydroxide.

Anusuya and Sathiyabama, (2016) studied the effect of chitosan on growth, yield and curcumin content in turmeric under field condition. The chitosan (0.1% w/v) was sprayed at a 30-day intervals upto 210 days. Chitosan application increased growth parameters (shoot height, leaf number per plant, plant fresh weight). Chitosan treatments enhanced yield and curcumin content. They concluded that chitosan can be used as eco-friendly compound to induce growth and curcumin content in turmeric.

Chintakovid et al., (2021) evaluated the curcuminoids, physiological adaptation and growth of the *Curcuma longa* L. under water stress and control temperature in glass house. In that experiment they found leaf osmotic potential reduced in 30 days in water-deficient under control temperature treatment, followed by 26.04% chlorophyll degradation, reduction in maximum photon quantum yield of PSII

(F_v/F_m) by 23.50%, 29.01% photon yield of PSII and declined photosynthetic rate by 89.39% over well water (control) under control condition. Curcuminoids content reduced by 40% and fresh and dry weight declined by 30-50% over normal temperature and well water treatment. Up-regulation of curcuminoids related genes (CURS1, CURS2, CURS3, and DCS) in control temperature and water deficient.

Chungloo et al., (2021) studied the regulation of curcuminoids, photosynthetic abilities, total soluble sugar and rhizome yield traits in two cultivars of turmeric (*Curcuma longa*) *via* foliar application of paclobutrazol.

Salicylic acid

Ghasemzadeh et al., (2012) recognized the involvement of salicylic acid in the production of secondary metabolites (flavonoids), Chalcone synthase (CHS) activity, antioxidant activity in two varieties of Malaysian ginger, *viz.* Halia Bentong and Halia Bara. The result showed the increment of chalcone synthase enzyme activity of Halia Bara at the 10^{-5} M concentration of salicylic acid. According to them as the concentration of salicylic acid decreases (10^{-3} M to 10^{-5}) the free radical scavenging power (FRAP) increased about 23% in Halia Bentong and 10.6% in Halia Bara. According to them the salicylic acid act as inducer as well as inhibitors of secondary metabolites and salicylic acid also increased the synthesis of flavonoids in ginger by foliar application under control environmental condition.

Ghasemzadeh and Jaafar, (2013) studied the effect of salicylic acid on physiological and antioxidant enzyme activity in ginger (*Zingiber officinale* Roscoe). They choose two varieties of ginger and applied salicylic acid in the foliar form. According to them the lower salicylic acid concentration was effective in the increasing photosynthetic rate, plant growth, antioxidant enzyme activities and proline content. Best result was found at the foliar application of salicylic acid at 10^{-5} M, with the enhanced catalase (20.1%), peroxidase (45.2%), superoxidase (44.1%) and proline (43.1%) activities.

Fayez and Bazaid, (2014) recognized the role of salicylic acid and potassium nitrate (KNO_3) in the drought and salinity stress in *Hordeum vulgare* L. cv. Gustoe. They selected the three levels of stress, 50, 100 and 150 mM for salinity and 50%, 70%, and 80% field capacity for drought stress. They found that the 50µM salicylic acid + 10 mM KNO_3 under 150 mM Nacl stress and 50% soil water content treated plants were improved physical and biochemically under salinity and drought stress.

Hoang et al., (2020) evaluated the physiological and phytochemical responses in *Amaranthus tricolor* L. by the foliar application of salicylic acid and calcium under salinity stress. They applied the calcium and salicylic acid individually or in combination, but they found the best result under the combined foliar application of the salicylic acid and calcium under salinity stress (100 mM). With the result of reduction of the adverse effects of salt stress by modulating the growth, sodium ion (Na+) exclusion from the root, and also increased the total phenolics, flavonoids and antioxidant activity.

Shemi et al., (2021) studied the effects of salicylic acid, zinc and glycine betaine on morpho-physiological growth and yield of maize under drought stress. They studied the relative efficacy of salicylic acid, zinc, and glycine betaine's foliar application on the morphological, chlorophyll contents, relative water content, antioxidant enzyme activity and yield attributes of maize plant exposed to two water conditions (85% field capacity: well watered, 50% field capacity: drought stress) during growth stages.

Calcium

Murillo-Amador et al., (2006) investigate the effect of foliar application of calcium nitrate on the growth, and physiological attributes of cowpea (*Vigna unguiculata* L. Walp.) under the salinity stress. They found the salt stress treated plant had reduced dry biomass, high sodium and chloride ion concentrations in plant parts, but low level of calcium magnesium and potassium concentration in salt treated plants. Foliar application of calcium nitrate was increased the chlorophyll fluorescence under salt treated plant. They were concluded that the foliar application was partially alleviating the negative effects of salt stress.

Xu et al., (2013) defined the effect of calcium chloride on growth, potassium, and antioxidant responses in *Zoysia japonica* under drought stress. They applied foliar application of calcium chloride solution (5, 10, and 20 mM) on leaves of *Zoysia japonica* for 3 days, followed by drought condition for 16 days. They found under stress (drought), calcium chloride pretreated plants had high fresh biomass (above ground), and fresh & dry biomass (below ground). Chlorophyll contents were found to be higher in the 5-, and 10-mM calcium chloride treated plant over the control, but the chlorophyll fluorescence (fv/Fm) and antioxidant enzyme was higher in the 10 mM calcium chloride treated plant.

Mukhtar et al., (2016) improved salt tolerance in Chili by the application of calcium and sulphur. They found the foliar application of calcium at 0.20 or 0.35 g/L and sulphur at 5 or 10 g/L improved the physiological and morphological characters in chili plant under salt stress. They concluded that the sulphur at the concentration of 10 g/L and calcium at 0.35 g/L can be used for the enhancement of salinity tolerance in chili plants.

Drought is the major problem in different part of the world as well as in Uttar Pradesh, India. Salicylic acid plays an important role in the stress tolerance, and also in the calcium signaling. The aim of the study to evaluate the role of foliar application of salicylic acid and calcium (individually or combined) in *Curcuma longa* L. under drought stress. To achieve this aim, we will conduct six experiments under the following objectives.

Objective

1. To study the effect of foliar application of salicylic acid on growth, physiological, biochemical, and yield parameters in *Curcuma longa* L.
2. To study the effects of foliar application of calcium on growth, physiological, biochemical, and yield parameters in *Curcuma longa* L.
3. To study the effect of Salicylic acid on growth, physiological, biochemical and yield parameters in *Curcuma longa* L. under drought stress.
4. To investigate the effect of foliar application of calcium on growth, physiological, biochemical and yield parameters in *Curcuma longa* L. under drought stress.
5. To study the combined effect of best concentrations of salicylic acid and calcium on growth, physiological, biochemical and yield parameters in *Curcuma longa* L.
6. To investigate the combined effect of best concentrations of salicylic acid and calcium on growth, physiological, biochemical and yield parameters in *Curcuma longa* L. under drought stress.

Proposed Methodology

Experiment location

The experiments will be conduct for the evaluation the effect of foliar application of salicylic acid and calcium alone and in combination under in normal and drought stress at Botanical garden, Dayalbagh Educational Institute, Dayalbagh Agra, Uttar Pradesh, India.

Soil analysis will be done for experiment

The following parameters will be analyzed after the treatments

1. **The growth parameters will be**

a. Plant height

b. Plant fresh weight

c. Plant dry weight

d. No. of leaves per plant

e. Leaf area

f. Stem diameter

2. **Physiological and biochemical parameters will be**

a. Total chlorophyll (Mackinney, 1941; Maclachlan and Zalik, 1963)

b. Total carotenoid content (Mackinney, 1941; Maclachlan and Zalik, 1963)

c. Nitrogen content in leaf and rhizome (Linder, 1944)

d. Phosphorous content in leaf and rhizome (Fiske and Subbarow, 1925)

e. Potassium content in leaf and rhizome (Hald, 1947)

f. Photosynthetic rate (by using Infrared Gas Analyzer)

g. Stomatal conductance (by using Infrared Gas Analyzer)

h. Relative water content (Barrs and Weattherley, 1962)

i. Proline content in leaf and rhizome (Bates et al., 1973)

j. Antioxidant enzyme activity (e.g. SOD, POD, CAT)

k. Electrolyte leakage

3. **The yield Parameters**

The essential oil will be extracted by the hydro-distillation using clevenger's apparatus and then quantified by gravimetrically according to Guenther (1972)

a. Essential oil content of leaves and rhizome per plant

Oil content will be estimated by following Formula

$$\text{Oil } \left(\%\frac{\text{v}}{\text{w}}\right) = \frac{\text{Observed volume of oil}}{\text{Weight of sample}} \times 100$$

b. Essential oil yield of leaves and rhizome

c. Curcumin content in leaves and rhizome

d. Curcumin yield in leaves and rhizome

4. Statistical analysis

Statistical analysis will be done by SPSS statistical software.

References

1. Aftab, T. (2019). A review of medicinal and aromatic plants and their secondary metabolites status under abiotic stress. *Journal of Medicinal Plants*, 7:99-106.
2. Akaberi, M., Sahebkar, A., & Emami, S. A. (2021). Turmeric and Curcumin: From Traditional to Modern Medicine. In *Studies on Biomarkers and New Targets in Aging Research in Iran* (pp. 15-39). Springer, Cham.
3. Akter, J., Hossain, M. A., Takara, K., Islam, M. Z., & Hou, D. X. (2019). Antioxidant activity of different species and varieties of turmeric (Curcuma spp): Isolation of active compounds. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, 215:9-17.
4. Anusuya, S., & Sathiyabama, M. (2016). Effect of chitosan on growth, yield and curcumin content in turmeric under field condition. *Biocatalysis and agricultural biotechnology*, *6*:102-106.
5. Asgher, M., Khan, M. I. R., Anjum, N. A., & Khan, N. A. (2015). Minimising toxicity of cadmium in plants—role of plant growth regulators. *Protoplasma*, 252:399-413.
6. Barrs H. D., Weattherley P. E. 1962. A re-examination of relative turgidity techniques for estimation water deficits in leaves. *Australian Journal of Biology Science,* 15:413-428.
7. Bastam, N., Baninasab, B., & Ghobadi, C. (2013). Improving salt tolerance by exogenous application of salicylic acid in seedlings of pistachio. *Plant growth regulation*, 69:275-284.
8. Bates, L. S., Waldren, R. P., & Teare, I. D. (1973). Rapid determination of free proline for water-stress studies. *Plant and soil*, 39:205-207.
9. Bonacina, C., da Cruz, R. M. S., Nascimento, A. B., Barbosa, L. N., Gonçalves, J. E., Gazim, Z. C., ... & de Souza, S. G. H. (2022). Salinity modulates growth, oxidative metabolism, and essential oil profile in *Curcuma longa* L. (Zingiberaceae) rhizomes. *South African Journal of Botany*, *146*:1-11.

10. Chempakam, B., & Parthasarathy, V. A. (2008). Turmeric. In V. A. Parthasarathy, B. Chempakam, & T. John Zacharraiah (Eds.), *Chemistry of spices* (pp. 97–123). Wallingford: CABI Publication.
11. Chintakovid, N., Tisarum, R., Samphumphuang, T., Sotesaritkul, T., & Cha-Um, S. (2021). Evaluation of curcuminoids, physiological adaptation, and growth of *Curcuma longa* under water deficit and controlled temperature. *Protoplasma*, 1-15.
12. Chungloo, D., Tisarum, R., Samphumphuang, T., Sotesaritkul, T., & Suriyan, C. U. (2021). Regulation of curcuminoids, photosynthetic abilities, total soluble sugar, and rhizome yield traits in two cultivars of turmeric (*Curcuma longa*) using exogenous foliar paclobutrazol. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *49*(3), 12445-12445.
13. Colpitts, C. C., Schang, L. M., Rachmawati, H., Frentzen, A., Pfaender, S., Behrendt, P., ... & Steinmann, E. (2014). Turmeric curcumin inhibits entry of all hepatitis C virus genotypes into human liver cells. *Gut*, 63:1137-1149.
14. Damalas, C. A. (2019). Improving drought tolerance in sweet basil (*Ocimum basilicum*) with salicylic acid. *Scientia horticulturae*, 246:360-365.
15. Das, K. (2016). Turmeric (*Curcuma longa*) oils. In *Essential Oils in Food Preservation, Flavor and Safety* (pp. 835-841). Academic Press.
16. Esmaeili, S., Barzegar, M., Sahari, M. A., Berenji-Ardestani, S., & Sheikhi, A. (2018). The effect of non-thermal processing on chemical constituents and antibacterial properties of turmeric rhizome volatile oil. *Journal of Food Process Engineering*, 41:e12827.
17. Fayez, K. A., & Bazaid, S. A. (2014). Improving drought and salinity tolerance in barley by application of salicylic acid and potassium nitrate. *Journal of the Saudi Society of Agricultural Sciences*, 13:45-55.
18. Fiske, C. H., & Subbarow, Y. (1925). The colorimetric determination of phosphorous. *Journal of Biological Chemistry*, 66:375-400.
19. Ghasemzadeh, A., & Jaafar, H. Z. (2013). Interactive effect of salicylic acid on some physiological features and antioxidant enzymes activity in ginger (*Zingiber officinale* Roscoe). *Molecules*, 18:5965-5979.

20. Ghasemzadeh, A., Jaafar, H. Z., & Karimi, E. (2012). Involvement of salicylic acid on antioxidant and anticancer properties, anthocyanin production and chalcone synthase activity in ginger (*Zingiber officinale* Roscoe) varieties. *International Journal of Molecular Sciences*, *13*:14828-14844.
21. Guenther, E. (1972). The essential oils: History, origin in plants, production. *Analysis*, 1: 147-151.
22. Hald, P. M. (1947). The flame photometer for the measurement od sodium and potassium in biological materials. *Journal of Biological Chemistry*, 167:499-510
23. Hay, E., Lucariello, A., Contieri, M., Esposito, T., De Luca, A., Guerra, G., & Perna, A. (2019). Therapeutic effects of turmeric in several diseases: An overview. *Chemico-biological interactions*, 310:108729.
24. Hoang, H. L., de Guzman, C. C., Cadiz, N. M., Hoang, T. T. H., Tran, D. H., & Rehman, H. (2020). Salicylic acid and calcium signaling induce physiological and phytochemical changes to improve salinity tolerance in red amaranth (*Amaranthus tricolor* L.). *Journal of Soil Science and Plant Nutrition*, 20:1759-1769.
25. https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=24824#null
26. Islam, F., Yasmeen, T., Arif, M. S., Riaz, M., Shahzad, S. M., Imran, Q., & Ali, I. (2016). Combined ability of chromium (Cr) tolerant plant growth promoting bacteria (PGPB) and salicylic acid (SA) in attenuation of chromium stress in maize plants. *Plant Physiology and Biochemistry*, 108:456-467.
27. Jahan, M. S., Wang, Y., Shu, S., Zhong, M., Chen, Z., Wu, J., ... & Guo, S. (2019). Exogenous salicylic acid increases the heat tolerance in Tomato (*Solanum lycopersicum* L) by enhancing photosynthesis efficiency and improving antioxidant defense system through scavenging of reactive oxygen species. *Scientia Horticulturae*, 247:421-429.
28. Kader, M. A., & Lindberg, S. (2010). Cytosolic calcium and pH signaling in plants under salinity stress. *Plant signaling & behavior*, 5:233-238.
29. Kebede, B. H., Forsido, S. F., Tola, Y. B., & Astatkie, T. (2021). Free radical scavenging capacity, antibacterial activity and essential oil composition of turmeric (*Curcuma domestica*) varieties grown in Ethiopia. *Heliyon*, 7:e06239.

30. Khan, M. I. R., Asgher, M., & Khan, N. A. (2014). Alleviation of salt-induced photosynthesis and growth inhibition by salicylic acid involves glycinebetaine and ethylene in mungbean (*Vigna radiata* L.). *Plant Physiology and Biochemistry*, 80:67-74.
31. Khan, M. I. R., Iqbal, N., Masood, A., Per, T. S., & Khan, N. A. (2013). Salicylic acid alleviates adverse effects of heat stress on photosynthesis through changes in proline production and ethylene formation. *Plant Signaling & Behavior*, 8:e26374.
32. Linder, R. C. (1944). Rapid analytical methods for some of the more common inorganic constituents of plant tissues. *Plant physiology*, 19:76.
33. Liu, J., and Zhu, K. (1997). An *Arabidopsis* mutant that requires increased calcium for potassium nutrition and salt tolerance. *Proc. Natl. Acad. Sci. U.S.A.* 941:4960–14964.
34. Mackinney, G. (1941). Absorption of light by chlorophyll solutions. *Journal of biological chemistry*, 140:315-322.
35. Maclachlan, S., & Zalik, S. (1963). Plastid structure, chlorophyll concentration, and free amino acid composition of a chlorophyll mutant of barley. *Canadian Journal of Botany*, 41:1053-1062.
36. Mattai, S. A. (2020). Turmeric: Anti-inflammatory Effects and Evidence for Use in Osteoarthritis. *Proceedings of UCLA Health*, *24*.
37. Meizarini, A., Aryati, W. R., & Puteri, A. (2018). Anti-inflammatory properties of a wound dressing combination of zinc oxide and turmeric extract. *Veterinary world*, *11*: 25.
38. Miura, K., & Tada, Y. (2014). Regulation of water, salinity, and cold stress responses by salicylic acid. *Frontiers in plant science*, 5:4.
39. Mukhtar, I., Shahid, M. A., Khan, M. W., Balal, R. M., Iqbal, M. M., Naz, T., ... & Ali, H. H. (2016). Improving salinity tolerance in chili by exogenous application of calcium and sulphur. *Soil & Environment*, *35*.
40. Murillo-Amador, B., Jones, H. G., Kaya, C., Aguilar, R. L., García-Hernández, J. L., Troyo-Diéguez, E., ... & Rueda-Puente, E. (2006). Effects of foliar application of calcium nitrate on growth and physiological attributes of cowpea (*Vigna unguiculata* L. Walp.) grown under salt stress. *Environmental and Experimental Botany*, 58:188-196.

41. Nair, K. P. (2019). The botany of turmeric. In *Turmeric (Curcuma longa L.) and Ginger (Zingiber officinale* Rosc.*)-World's Invaluable Medicinal Spices* (pp. 7-35). Springer, Cham.
42. Nair, M. K., Nambiar M. C., Ratnambal, M .J. (1980). Cytogenetics and crop improvement of ginger and turmeric. In *Proceedings of the national seminar on ginger and turmeric* (pp. 15–23). Calicut, India.
43. Nazar, R., Umar, S., & Khan, N. A. (2015). Exogenous salicylic acid improves photosynthesis and growth through increase in ascorbate-glutathione metabolism and S assimilation in mustard under salt stress. *Plant signaling & behavior*, 10:e1003751.
44. Nelson, K. M., Dahlin, J. L., Bisson, J., Graham, J., Pauli, G. F., & Walters, M. A. (2017). The essential medicinal chemistry of curcumin: miniperspective. *Journal of medicinal chemistry*, 60:1620-1637.
45. Ogidi, C. O., Ojo, A. E., Ajayi-Moses, O. B., Aladejana, O. M., Thonda, O. A., & Akinyele, B. J. (2021). Synergistic antifungal evaluation of over-the-counter antifungal creams with turmeric essential oil or Aloe vera gel against pathogenic fungi. *BMC Complementary Medicine and Therapies*, 21:1-12.
46. Panja, B. N., De, D. K., Basak, S., & Chattopadhyay. (2002). Correlation and path analysis in turmeric (*Curcuma longa* L.). Journal of Spices and Aromatic Crops, 11:70–73.
47. Prajapati, S. K., Mishra, G., Malaiya, A., Jain, A., Mody, N., & Raichur, A. M. (2021). Antimicrobial Application Potential of Phyto-constituents from Turmeric and Garlic. In *Bioactive Natural Products for Pharmaceutical Applications* (pp. 409-435). Springer, Cham.
48. Reddy, M. L. N. (1987). Genetic variability and association in turmeric (*Curcuma longa* L.). Progress in Horticultural Science, 19:83–86.
49. Sandeep, I. S., Sahoo, B. C., Singh, S., Sahoo, S., Nayak, S., & Kar, B. (2021). Environmental Factors Influencing Yield and Quality of Essential Oils in *Curcuma longa* cv. Lakadong. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, 91:761-767.

50. Sedaghat, M., Sarvestani, Z. T., Emam, Y., Bidgoli, A. M., & Sorooshzadeh, A. (2020). Foliar-applied GR24 and salicylic acid enhanced wheat drought tolerance. *Russian Journal of Plant Physiology*, 67:733-739.

51. Shaki, F., Maboud, H. E., & Niknam, V. (2018). Growth enhancement and salt tolerance of Safflower (*Carthamus tinctorius* L.), by salicylic acid. *Current Plant Biology*, 13:16-22.

52. Shemi, R., Wang, R., Gheith, E. S., Hussain, H. A., Hussain, S., Irfan, M., ... & Wang, L. (2021). Effects of salicylic acid, zinc and glycine betaine on morpho-physiological growth and yield of maize under drought stress. *Scientific Reports*, *11*:1-14.

53. Singh, G., Kapoor, I. P. S., Singh, P., de Heluani, C. S., de Lampasona, M. P., & Catalan, C. A. (2010). Comparative study of chemical composition and antioxidant activity of fresh and dry rhizomes of turmeric (*Curcuma longa* L.). *Food and chemical toxicology*, *48*:1026-1031.

54. Tilak, J. C., Banerjee, M., Mohan, H., & Devasagayam, T. P. A. (2004). Antioxidant availability of turmeric in relation to its medicinal and culinary uses. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, 18:798-804.

55. Vineeth, D., Venkateshwar, C., & Unnisa, S. A. (2014). Treatment of *Curcuma longa* (Turmeric) Contaminated with Heavy Metals. *World Journal of Pharmaceutical Research*, *3*:460-468.

56. Wang, C., Zhang, S., Wang, P., Hou, J., Qian, J., Ao, Y., et al. (2011). Salicylic acid involved in the regulation of nutrient elements uptake and oxidative stress in *Vallisneria natans* (Lour.) Hara under Pb stress. *Chemosphere*, 84:136–142.

57. Xu, C., Li, X., & Zhang, L. (2013). The effect of calcium chloride on growth, photosynthesis, and antioxidant responses of *Zoysia japonica* under drought conditions. *PloS one*, *8*:e68214.

58. Yang, Q. Q., Cheng, L. Z., Zhang, T., Yaron, S., Jiang, H. X., Sui, Z. Q., & Corke, H. (2020). Phenolic profiles, antioxidant, and anti-proliferative activities of turmeric (*Curcuma longa*). *Industrial Crops and Products*, 152:112561.